

Hot Section Silicon Nitride Materials Development For Advanced Microturbines and Other Gas Turbine Component Applications

ASME/IGTI Turbo Expo

Ceramic Components for Microturbines

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Hot Section Materials Development For Advanced Microturbines Program

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Purpose of the Work

Hot Section Si_3N_4 for Advanced Microturbine Program

- > Under DOE/ORNL Program, Develop and improve a cost-effective, reliable monolithic silicon nitride material for Hot Section Components in DER Advanced Microturbine Systems
- > Through surface engineering, demonstrate sufficient environmental stability for operation w/o EBC -- Or compatible with EBC

Overall Goals

- > Contribute to AMTS Objectives of efficiency, fuel flexibility, durability, operating cost
- > Expand utility of HT silicon nitride component for other power generation and military applications

History - Ceramic Gas Turbine

DoD Ceramics for High Performance Applications

- > 70's & 80's: Army Conferences, NAVAIR Bearings
- > NC-132 HPSN

DOE Automotive Gas Turbine Programs (80's-90's)

- > Allison, AlliedSignal Primes
- > Norton/TRW NT154 SN, ASCC, Kyocera, Carborundum SiC



Strength Prediction - Weibull 2p vs. 3p

NCX-5102 4%Y-Si₃N₄ Exhibits 3-parameter Weibull distribution

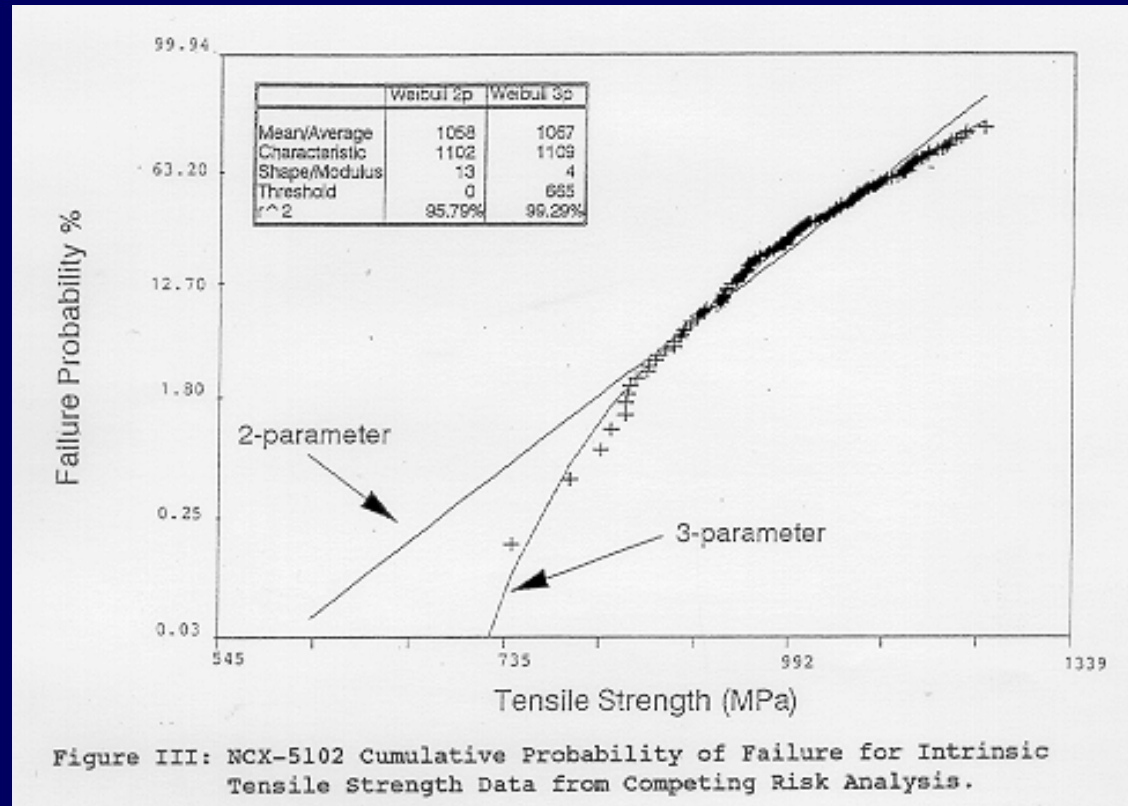
.25" Buttonhead
Tensile rods

320 data points

With 3-parameter

> 1057 MPa mean

> 685 MPa
Threshold



Pujari, et al. (Norton Company), "Development of Improved Processing and Evaluation Methods for High Reliability Structural Ceramics for the Advanced Heat Engine Applications, Phase I", August 1993, p. ix.

Life Prediction - High Temperature

Load, Time, Temperature, and Environmental Effects

- Creep
 - Plastic deformation

NT154 Si_3N_4

Liu, Stevens, and Brinkman (ORNL), "Tensile Stress-Rupture Development", Ceramic Technology Project Bimonthly Technical Progress Report, October 30, 1993, p. 58.

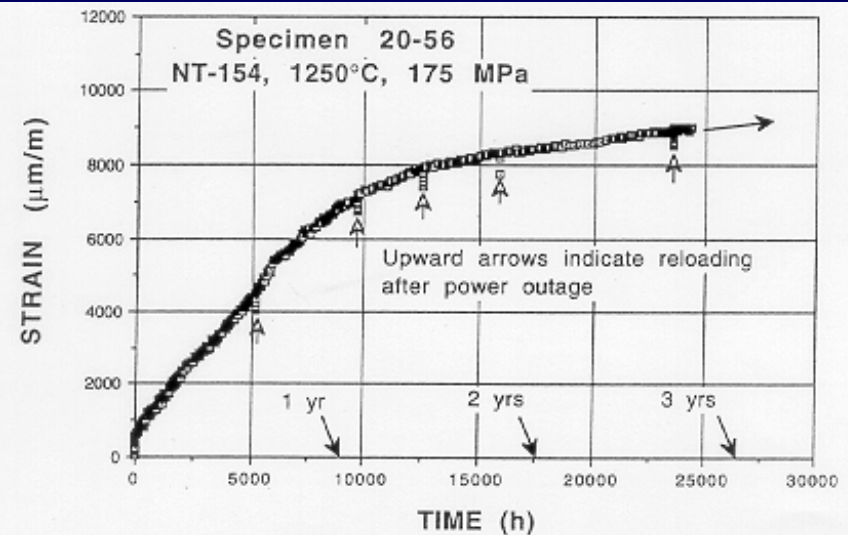


Fig. 3. Creep curve of NT-154 Si_3N_4 (specimen 20-56) tested at 1250°C and 175 MPa. No indication of imminent failure has been observed after nearly three years of testing.

Material and Process Approach

Ceramic Microturbine Technology

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graph TD; A[Ceramic Microturbine Technology] --> B[Material Development]; A --> C[Net Shape Forming Development]; B --> B1[• Re-establish NT154]; B --> B2[• Improve NT154]; B --> B3[• Recession Control]; B --> B4[• Alternate Composition]; C --> C1[• Green CNC Machining]; C --> C2[• Casting / Molding];
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Material Development

- **Re-establish NT154**
- **Improve NT154**
- **Recession Control**
- **Alternate Composition**

Net Shape Forming Development

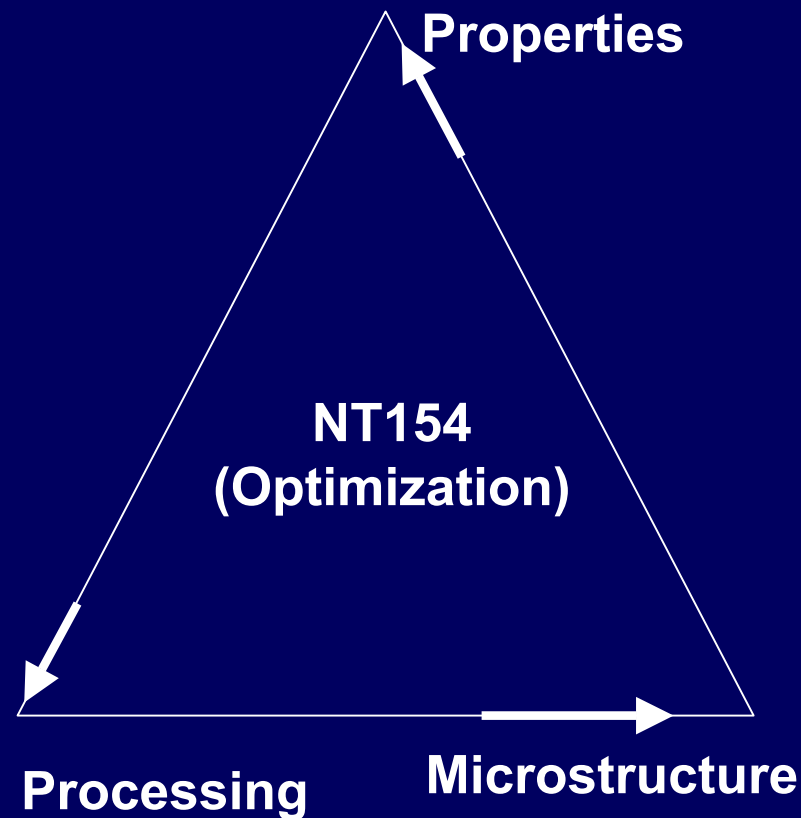
- **Green CNC Machining**
- **Casting / Molding**

Materials Development Objective

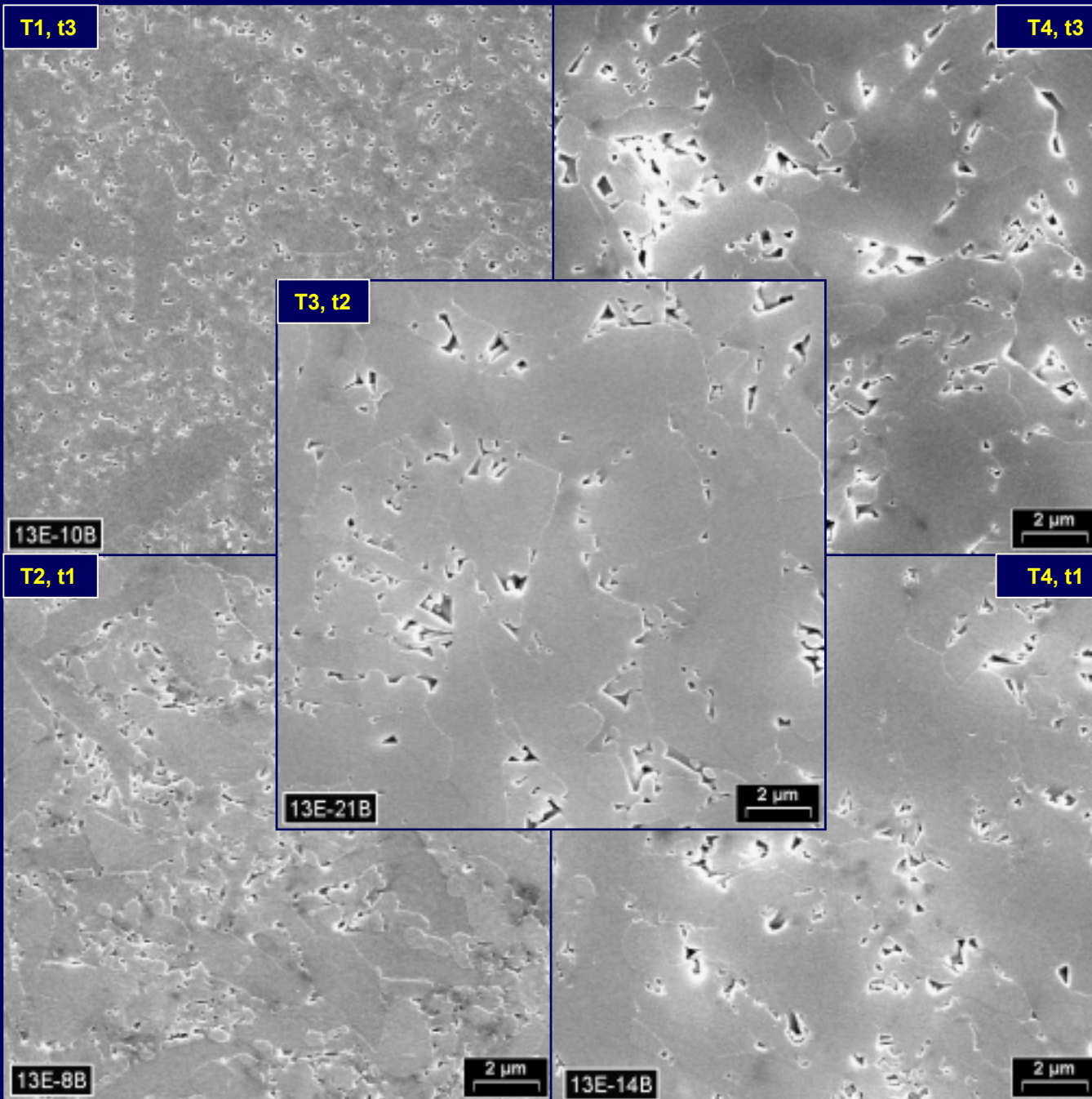
Develop and optimize a high temperature ceramic material and process suitable for microturbine applications up to 1300°C.

Specific Properties

- **Fast Fracture**
 - RT – $\sigma \geq 950$ MPa
 - 1300°C $\sigma \geq 600$ MPa
- **Fracture Toughness** $\geq 6.0 \text{ MPa}\sqrt{\text{m}}$
- **Weibull Modulus** ≥ 10
- **High Temperature Creep Rate**
 $\approx 1.9 \times 10^{-8}/\text{s}$ @ 1260°C/300 MPa
- **Oxidation Resistance up to 1250°C**
- **Recession Resistance in humid environment up to 1250°C**



HIP DOE Microstructures



Typical Ceramic Processing



Powder Processing



Forming



Green Machining



Firing



Machining



Inspection



In-process control

Process Examples

Milling, Blending
Slurry Prep, Spray
Drying, Freeze
Granulation

Dry Forming, Casting,
Solid Casting/IM/TC,
Layer Processing/RP

CNC, Flank Milling

Pressureless Sintering,
GPS, HIP, HP

Diamond Grinding,
Lapping, Polishing

Complex Green Machining Trials

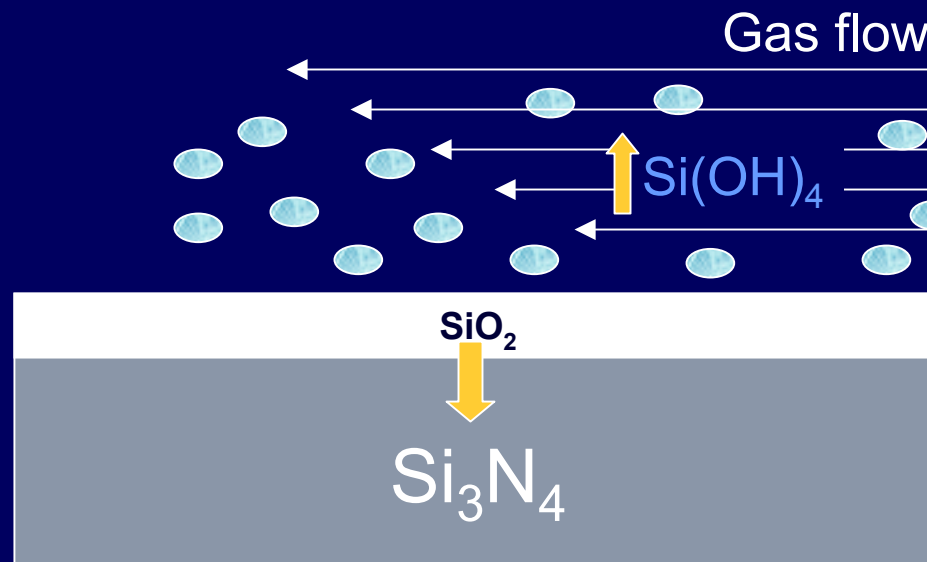


- **Preliminary trials**
 - 0.9-1.0 μm Ra hub
 - 1.4-1.9 μm Ra blades
- **Surface finish can be controlled**
- **Uniform/isotropic shrinkage**
- **High yield**
- **Good for prototype quantities**

Recession

Mechanism

Volatilization of SiO_2 leads to recession of
Si-Based Advanced Ceramics



Recession Control

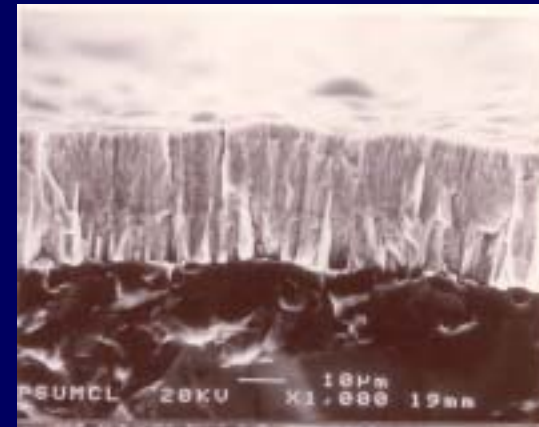
Surface Protection

Surface Modification (HEEPS)

- > Development of protective coating during the glass HIPing process step.
 - Coat then densify
 - In-situ formation

EBC

- > Post-densification application of a protective layer (ex. CVD, EB-PVD)



Dense Y_2O_3 on SiC by EB-PVD

Summary and Conclusions

Si₃N₄ potential enabling material for high efficiency advanced microturbines

- > High perf. industrial, transportation and military applications
- > Ceramic suppliers, engine builders, national labs, and government

Saint-Gobain Program re-introducing NT154 family

- > Baseline properties achieved internally
- > Forming development underway: Two Approaches
- > Qualification on-going at ORNL
- > Improvements to NT154 being investigated

Challenge of Environmental Stability in GT

- > Developing recession control strategies
- > Novel in-situ surface modification approach
- > EBC development